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DESIGN TECHNIQUES FOR IMPROVING THE UNIFORMITY AND LONG-TIME ST--ETC(U)  
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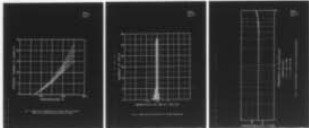
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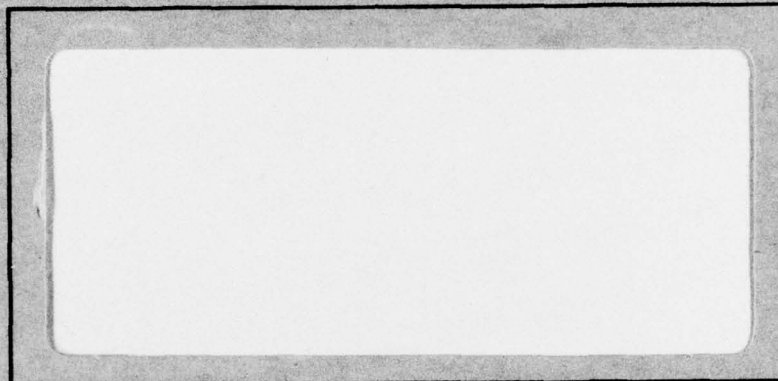
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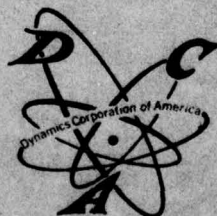


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6 DESIGN TECHNIQUES FOR IMPROVING THE  
UNIFORMITY AND LONG-TIME STABILITY  
OF CERAMIC TRANSDUCERS

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This report covers the material presented  
by Frank Massa at the U. S. Navy Seminar  
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Piezoelectric ceramics have found wide spread application in many sonar transducer designs, and although tens of thousands of ceramic transducers of various types have been built over the past decade, there is considerable ambiguity regarding the variations in their performance characteristics under different environments. There has been very little authoritative engineering data available to indicate the exact behavior of the various types of ceramics under varying conditions of use, and in the absence of such data, many transducer designs have proved disappointing in their reliability over long periods of time.

Some of the more difficult problems encountered in the design and manufacture of ceramic transducers concern the achievement of uniformity and long-time stability of the elements, especially for such critical applications in which beam forming networks are employed with the structures. There are two general classes of inherent difficulties that must be overcome; namely, to neutralize the relatively large variations in sensitivity and impedance of the ceramics during the initial production of the transducer elements, and to minimize the variations in aging characteristics that occur among the ceramic elements over the useful life of the transducer.

Barium titanate is the oldest of the commercially available ceramics and it has been used extensively in hydrophone designs because the operating temperature rise for this application is negligibly small and, therefore, no great risk is involved in depolarizing the ceramic elements, such as might occur in connection with the use of barium titanate for high powered transmitting transducers. In the design of barium titanate hydrophones requiring a high degree of uniformity, such as is necessary in beam forming arrays, it is essential to employ a plurality of ceramic elements ↗

in each hydrophone unit in order to suitably average out the relatively wide individual variations in sensitivity and capacity that are normally found within a group of polarized ceramic elements. The typical normal range of variation in capacity within a large production lot of high quality polarized barium titanate elements is approximately 25%, and the corresponding variation in sensitivity within the lot is about 4 db.

Experimental data showing the measured sensitivity for 30,000 barium titanate cylinders manufactured to close mechanical tolerances is plotted in Fig. 1. It is obvious from the data that it would be impossible to produce hydrophones having uniform sensitivity if the design were to employ a single cylinder for each hydrophone. To overcome the difficulty presented by these variations, it is necessary that each hydrophone assembly employ several ceramic elements which are individually calibrated for both sensitivity and capacity and then combined into selected groups, each group having the same average sensitivity and capacity of the entire production lot.

Even after careful selection of the ceramic elements, it will be found that the individual hydrophone characteristics will age differently and, therefore, several initially well-balanced assemblies cannot be assured of remaining balanced at some future time subsequent to their manufacture. Since the aging of the various parameters are logarithmic functions of time, greater variations will occur within the first few months after polarization. Therefore, where uniformity and stability are important requirements, it is essential that the calibration and selection of the individual ceramic elements be made several months following the date of polarization.

The lead-zirconate-titanate ceramics are generally more stable than barium titanate and, therefore, somewhat better performance may be



expected in the use of this material. However, although the stability of the lead zirconates is generally higher, a considerable variation may be expected among the various types of zirconates. In general, the same comments that were made concerning the variations in barium titanate ceramics would also apply, except for the fact that the depolarization risk would be considerably reduced for high-power transmitters because of the higher Curie points of the zirconates.

If a transducer array is to operate over a range of temperatures, such as is commonly encountered in various parts of the ocean, the selection of the ceramics at any particular temperature will not necessarily insure the same relative uniformity at another temperature. An example of the relative differences that are typical among selected zirconate elements as they are cycled over the temperature range  $4^{\circ}\text{C}$ . to  $30^{\circ}\text{C}$ . are shown in the experimental data which follow. Fig. 2 shows the variations in capacity of three PZT-5 cylinders as they are successively cycled between the temperature range  $4^{\circ}\text{C}$ . and  $30^{\circ}\text{C}$ . Fig. 3 shows similar data for three matched PZT-5H cylinders of the same dimensions. Two things are obvious from these data; first, that the change in capacity is not the same for each cylinder nor is it the same for a particular cylinder during successive cycles of the same changes in temperature.

The PZT-5 type zirconates show higher internal losses at high power levels than do the PZT-4 type zirconates. Therefore, PZT-4 is generally preferable for high-power sonar applications. Fig. 4 shows the variation of capacity with temperature among four normal PZT-4 polarized ceramic cylinders that were matched at  $70^{\circ}\text{F}$ . It can be seen that the relative non-uniformity among the four cylinders increases from 1% at  $100^{\circ}\text{F}$ . to 14% at  $250^{\circ}\text{F}$ .



In order to cope with the inherent problems of non-uniformity among polarized ceramic elements, it is essential that the requirements of each transducer application be very carefully analyzed before selecting the type of ceramic best suited for the job, or before even assuming that the design should employ ceramics as the satisfactory transducer material. It is also extremely important that when ceramics are employed in transducer designs which require a high degree of uniformity among the elements, a pre-aging process must be imposed on the ceramics followed by a calibration procedure which permits the classification of the ceramics into selected groups. Another important requirement for increasing the uniformity and stability of the design is to employ several ceramics in each transducer element which are selected and matched in a manner that will minimize the random variations insofar as they affect the subsequent performance of the transducers. For many applications where exact beam forming characteristics are not essential and for applications where the uniformity of impedance among a multiple assembly of transducer elements is not important, polarized ceramics may be employed without the selection procedures which have been discussed, and for such cases polarized ceramics will present useful advantages in the design of sonar transducers.

It is unfortunate that the general use of polarized ceramics during the past decade has prevented many transducer engineers from becoming acquainted with the advantages of a piezoelectric material whose characteristics are far superior to the polarized ceramics where uniformity and long time stability are basic requirements of the sonar transducer. The material is ammonium di-hydrogen phosphate which was developed and grown commercially in very large quantities during the early 1940's, and it quickly super-

seded Rochelle salt for practically every sonar transducer application. Unfortunately, not too many engineers became familiar with its excellent characteristics nor, more importantly, did they become familiar with the production engineering techniques which are needed in the handling and processing of the material to achieve transducer structures of extreme ruggedness.

For many critical applications, ADP will permit a degree of uniformity and long-time stability in sonar transducers that cannot be achieved by ceramics. A typical indication of the uniformity that can be realized in the manufacture of ADP transducers is indicated in Fig. 5 which shows the sensitivity distribution among 130 ADP transducers. The total spread in sensitivity among all the units in the group is only 1/2 db, which is a degree of uniformity that is extremely difficult to obtain with ceramic designs. Only by careful selection and matching following long prior aging of the ceramic elements, is it possible to approach the high degree of uniformity that is inherent in ADP. It should be recognized, however, that the high uniformity can only be realized with the matched ceramic design at a chosen fixed set of environmental conditions, and the uniformity may deteriorate at a different temperature or hydrostatic pressure.

The excellent long-range stability of ADP is illustrated in Fig. 6 which shows two calibration curves of a low cost ADP sonobuoy hydrophone. One calibration was made at the time of manufacture and the second one made approximately six years later.

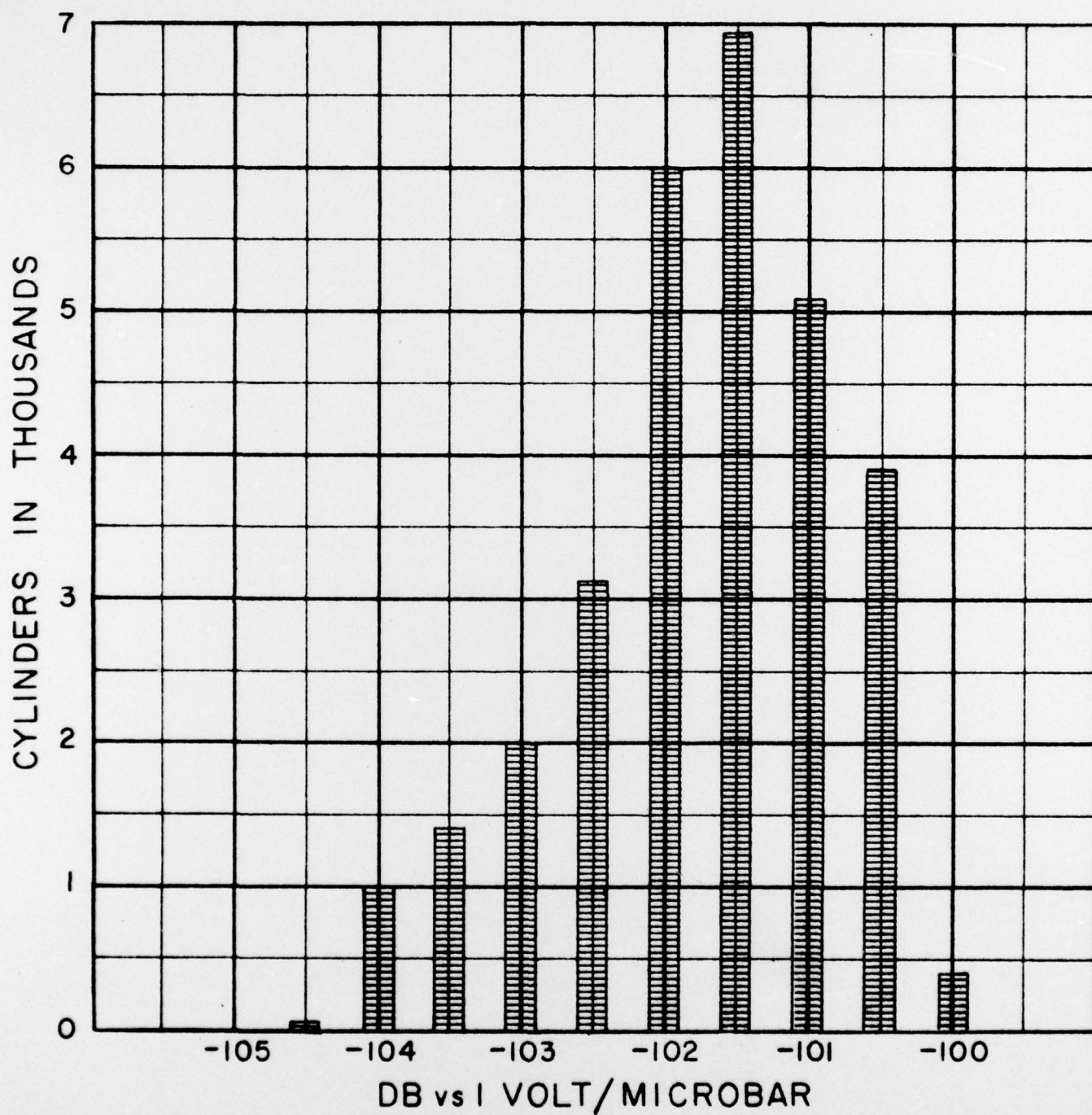


Fig. 1 Sensitivity Distribution for 30,000 Barium Titanate Cylinders



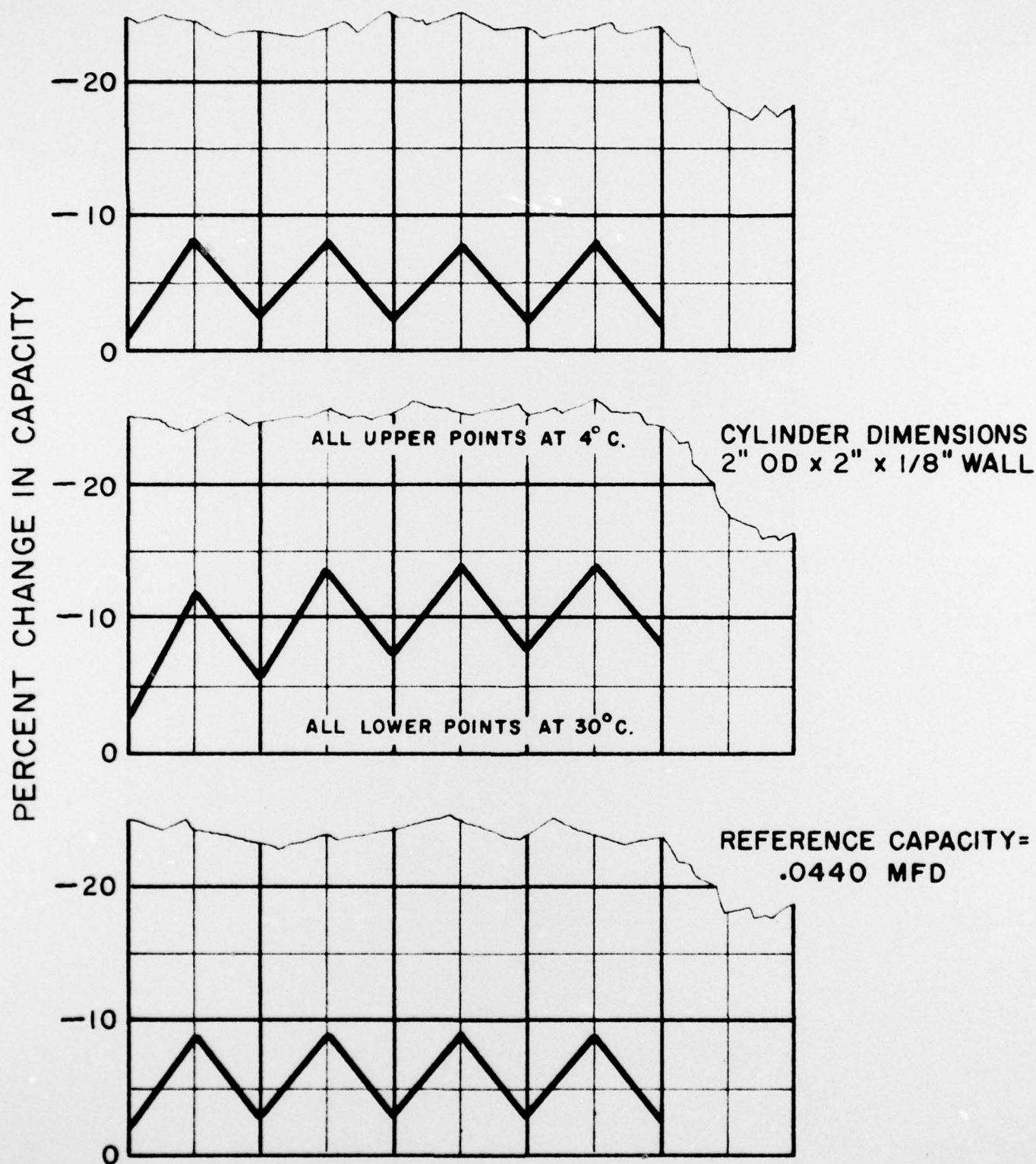


Fig. 2 Cyclic Variation in Capacity of Lead-Zirconate-Titanate Cylinders (Type 5)

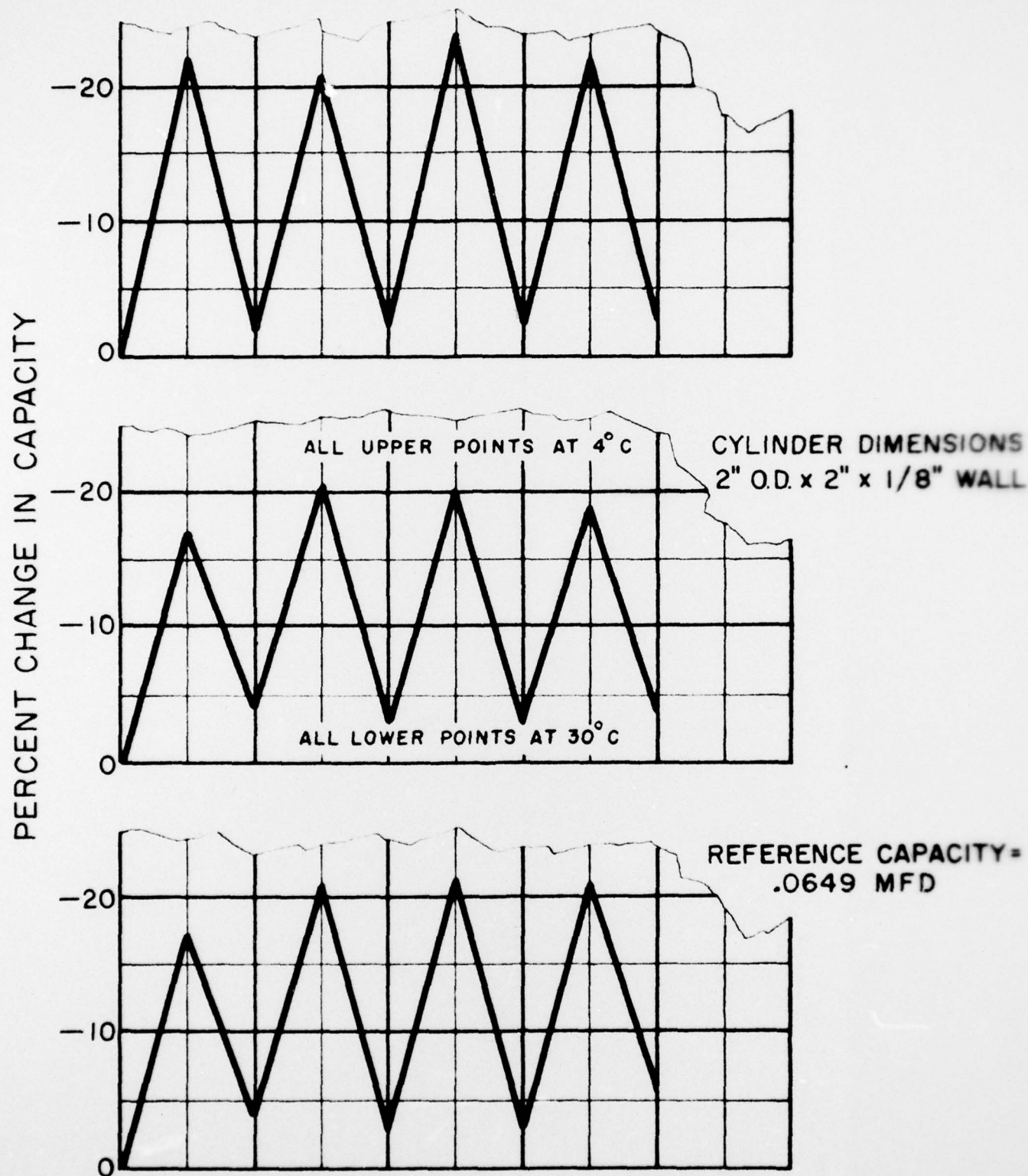


Fig. 3 Cyclic Variation in Capacity of Lead-Zirconate-Titanate Cylinder (Type 5H)

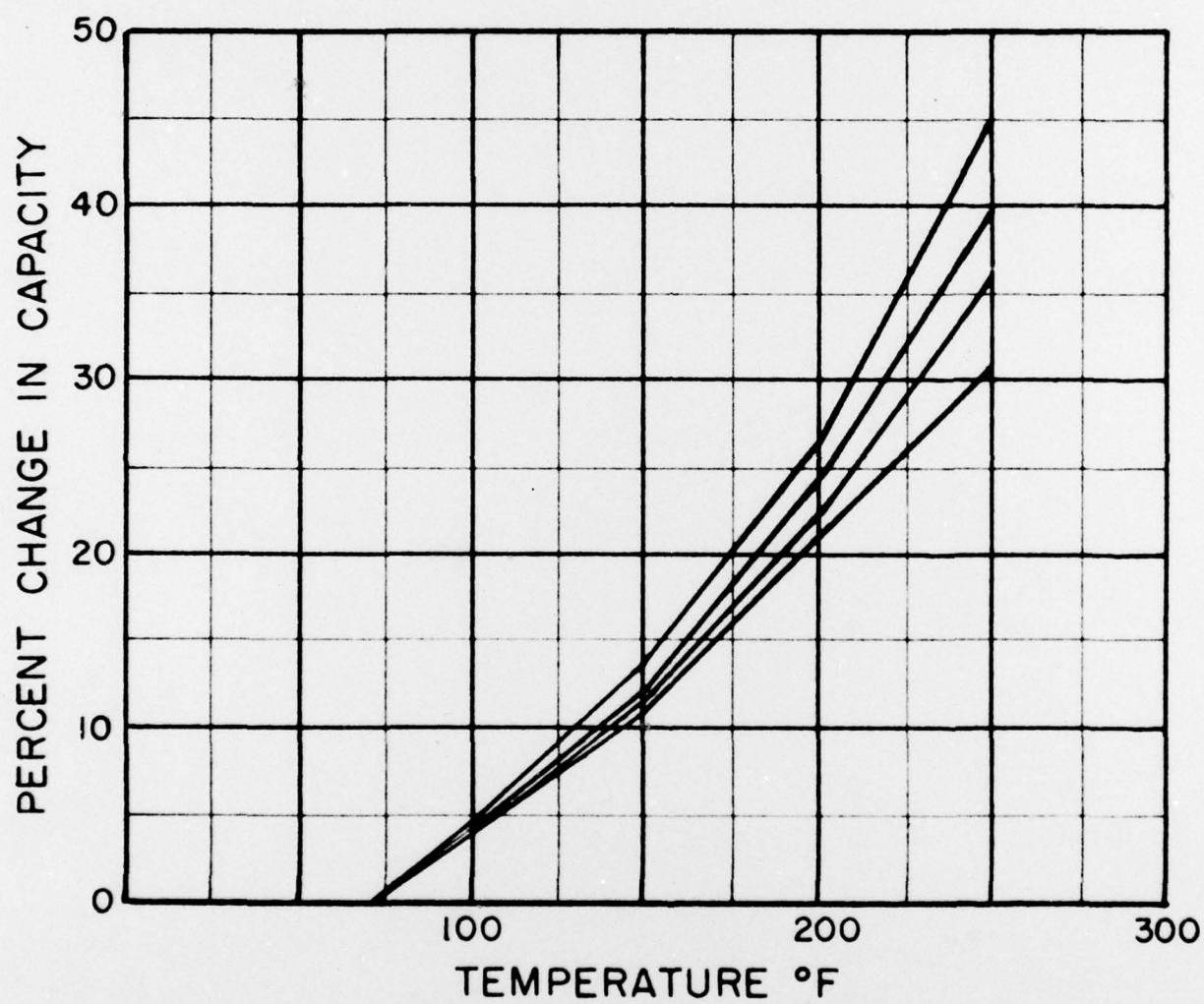


Fig. 4 Capacity vs. Temperature for Typical PZT-4 Cylinders  
Taken from a Selected Normal Production Group



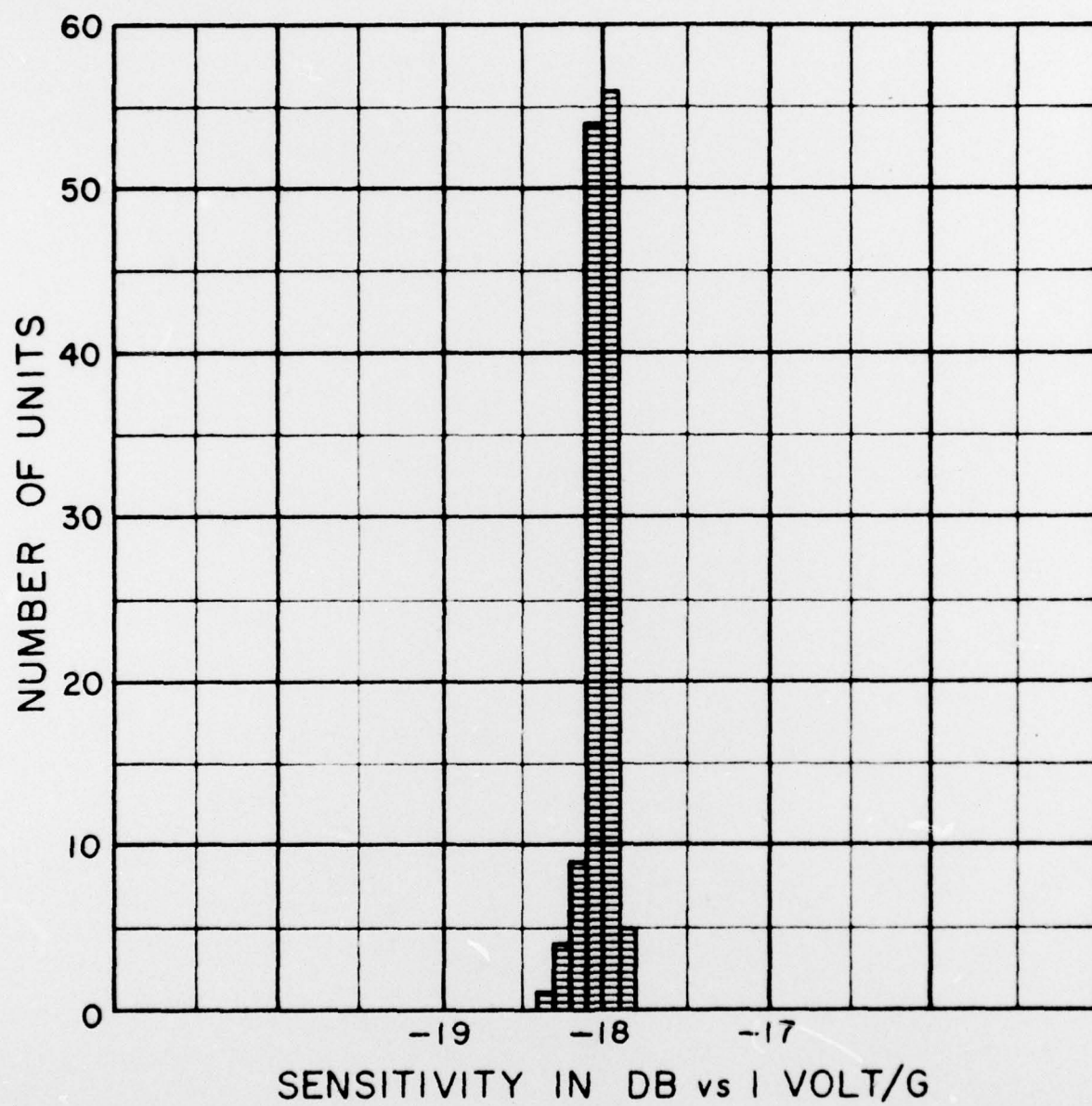


Fig. 5 Sensitivity Distribution for 130 ADP Transducers

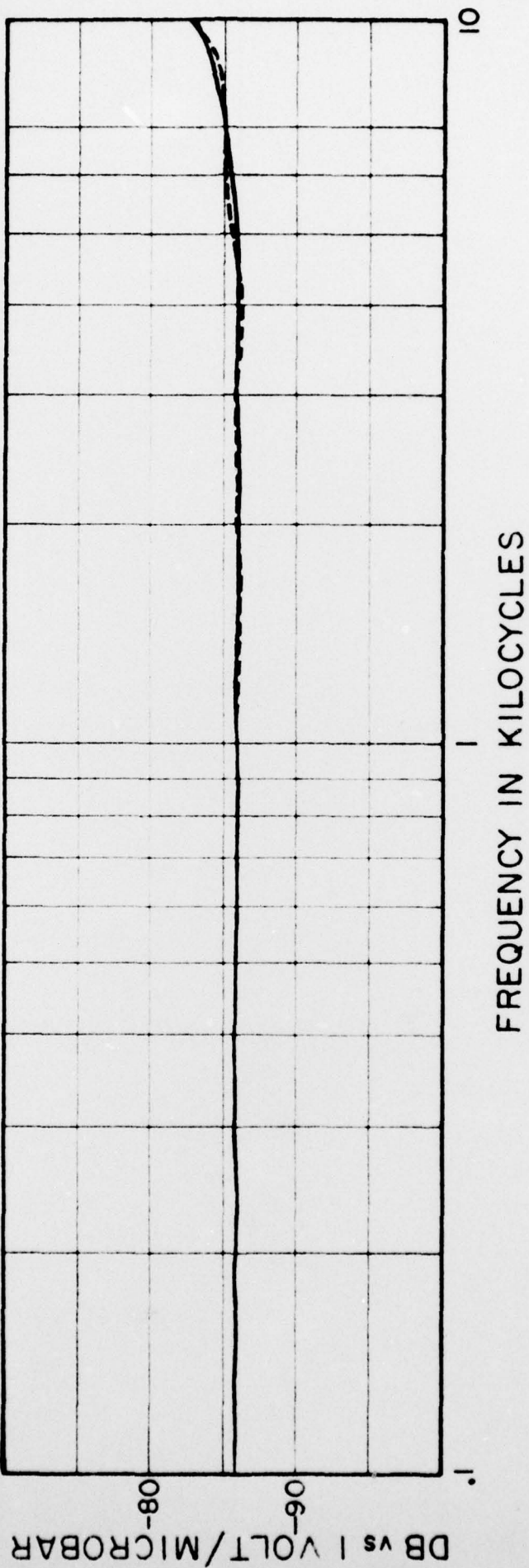


Fig. 6 Receiving Response of Low Cost ADP Sonobuoy Hydrophone